# ENERGETICS OF CAPTIVE HOUSE MICE, (*MUS MUSCULUS* L.), FED TWO DIFFERENT FOODS

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**ABSTRACT**

The energetics of captive house mice fed two separate foods, sheep nuts and dog biscuits, were studied and compared. Short term experiments on food consumption, assimilation, and metabolism were made and the results combined in the form of energy budgets for representative 12 and 25 g mice. Growth of three litters fed the experimental foods was also determined. Mice fed sheep nuts consumed more, assimilated a higher percentage of the food and grew to a greater size. As growth rates of young mice fed the two foods were similar it seems that sheepnut-fed mice were using more energy in respiration, probably due to higher levels of activity.

## INTRODUCTION

The energy taken in by an animal is required for two purposes: (1) to provide energy for the normal life processes and (2) to provide for the increase of biomass, i.e., production (Meese 1971). The fate of consumed energy can be examined by compiling an energy budget. Using I.B.P. terminology (Petrusewicz 1967) the energy budget of a population is given by the equation:

$$C = P + R + F + U$$

where $C$ is consumption, $P$ is production, $R$ is respiration, $F$ is faeces and $U$ is excreta (urine and other exudates). In addition,

$$D = P + R + U$$

and $$A = P + R$$

where $D$ is digestion and $A$ is assimilation.

Assimilated energy is also referred to as *energy flow* and it can be measured either by determining metabolism and tissue production (i.e., $R + P$) or by measuring food intake minus egesta (i.e., $C - F$). The latter is by far the most widely adopted method in small mammal studies and has become known as the "balance" method.

This paper deals with a series of laboratory experiments with the house mouse *Mus musculus* L., from which energy budgets have been constructed and compared for confined mice fed two different foods.

## METHODS

Mice used in the experiments were reared in the laboratory. They were, however, derived from wild stock obtained several months previously.

## LONG TERM GROWTH EXPERIMENTS

Three litters of mice (one in 1971 and two in 1972) were kept in separate metal-mesh cages 530 x 180 x 280 mm at room temperature (20-25°C) which was a little below the temperature of thermoneutrality for the white mouse (32°C; Pennycuik 1967). Water was supplied continuously and known amounts of food, commercially produced dog biscuits or sheep nuts manufactured by Brown Bros. of Christchurch, were provided, always in excess of the needs of the mice. Cotton wool was used as bedding. All mice were marked by toe or ear clipping and were weighed to the nearest 0.1 g once or twice a week for 10-13 weeks. Mice at the start of the study were just weaned. Mean biomass growth (gross production) per mouse in each litter was determined by summing all increases in weight obtained at each census time and dividing by the number of mice present. Unfortunately, numbers in the three litters which were initially 14 (1971), 9 and 10 (1972) were reduced during the growth period by the loss of some mice.

## FEEDING EXPERIMENTS

Short term feeding experiments were run over 48-72 hour periods. Mice which had been fed for some time previously on the experimental food were kept in pairs in metal-mesh cages as in the long term experiments (1972) or in 5 l plastic canisters (1971). They were provided with water but not bedding as it is difficult to separate crumbs and faeces from cotton wool. The mice were weighed at the start of a run and were fed a weighed amount of sheep nuts or dog biscuits. At the end of the experiment they were weighed again and all uneaten food and faeces produced were collected, dried and weighed. In experiments in cages with wire-mesh floors, the amount of fine food material spilled through the mesh was determined separately from the larger uneaten fraction. By determining the ratio of food offered to food spilled a correction factor was found for estimating food consumed in the long term growth studies.

## FOOD AND WATER DEPRIVATION EXPERIMENTS

To examine the effect of food and water deprivation on mouse weight, pairs of mice were kept for 24 hr in plastic canisters at 24°C with either food (sheep nuts) only, water only, food and water, or nothing. Mice were weighed at the start and end of each experiment.

## RESPIRATION

Short term measurements of respiration were made at room temperature (20-24°C) using closed respirometers constructed from 202 mm (8 inch) diameter desiccators. Two mice were placed in each respirometer and changes in pressure within the apparatus were measured on a syringe attached to a manometer containing a detergent-dye mixture. NaOH placed beneath the false floor of the desiccator absorbed $CO_2$ evolved. Readings were made at 2-16 minute intervals for varying periods of time up to 1 hr, with animals in various states of activity. Between runs the whole

apparatus was flushed with air. In estimating the energy of respiration a respiratory quotient of 0.8 and an oxycaloric coefficient of 4.8 kcal/l oxygen were assumed (Grodzinski and Gorecki 1967).

## CARCASS ANALYSES AND CALORIMETRY

Calorific values of food, faeces and dry mouse tissue were determined with a Parr oxygen bomb calorimeter. The dry matter content of four mice was determined by drying to constant weight and the dry weight:live weight ratio thus obtained was used to estimate the energy content of mouse tissue on a dry weight basis.

Fat content of mice was determined by extraction of dried, ground tissue with petroleum ether in a Soxhlet apparatus, and on one occasion total lipid was determined by extraction with chloroform:methanol (1:1) in filter funnels. At the end of an extraction the residue was dried and weighed and the fat percentage determined by subtracting the final from initial weight.

# RESULTS

## FOOD, FAECAL AND CARCASS ANALYSES

Calorific values of mouse tissue, foods and faeces produced by mice fed the experimental foods are given in Table 1. Little

TABLE 1. CALORIFIC VALUES OF EXPERIMENTAL FOODS, FAECES AND MOUSE TISSUE OBTAINED IN THIS STUDY

| Material | kcal/g dry wt |
|---|---|
| Sheep nuts | 4.55 |
| Dog biscuits | 4.50 |
| Faeces (fed sheep nuts) | 4.33 |
| Faeces (fed dog biscuits) | 4.38 |
| Mice | 5.20, 5.72, 5.96, 6.32 |

difference in energy content was found between foods. The calorific values of faeces were slightly lower than those of the foods suggesting that a higher proportion of the higher energy components of the foods (e.g., fats) were being digested. This is contrary to the findings of Meese (1971) who found that the bank voles, *Clethrionomys glareolus*, did not utilize the high energy content of their food, and thus the calorific value of their faeces was higher than that of the food.

The high calorific values for mouse tissue were comparable with those given by Cummins (1967) and Vinegar et al (1970) for laboratory white mice. Values given in the literature indicate that the energy content of mice can vary considerably. The highest value obtained in this study (6.32 kcal/g) was obtained for mice with a very high (55%) fat content as measured by chloroform:methanol extractions. Assuming a dry matter content of 38%

(see below) live mouse tissue had a calorific value of 1.4-1.6 kcal/g live weight which is in good agreement with the estimate of 1.5 kcal/g given by Gorecki (1965).

The dry weights of four mice ranging from 16-22 g live weight were found to be 38±2% of live weight. A fat content of 34±2% dry weight was obtained for four late juvenile and adult mice extracted with petroleum ether. Lipids represented 55±0.5% of dry weight of four mice extracted with chloroform:methanol.

## DAILY ENERGY FLOW

From the food consumption experiments energy flow (i.e., assimilated energy) through individual mice was calculated on a daily basis (Table 2). Digested energy was calculated from food consumed minus faeces produced, and energy assimilated was calculated on the assumption that 3% of the digested energy was lost as urine (Meese 1971).

TABLE 2. MEAN VALUES OBTAINED IN FEEDING EXPERIMENTS

All results expressed as (kcal/g mouse)/day

| Mice | No. of exptl pairs | Food | Consumption | Faeces | Assimilation | % assimilation |
|---|---|---|---|---|---|---|
| Adults (> 20 g) | 5 | Sheep nuts | 1.04 | 0.11 | 0.89 | 85 |
| " | 1 | Dog biscuits | 0.87 | 0.17 | 0.67 | 77 |
| Juveniles | 3 | Sheep nuts | 2.02 | 0.20 | 1.72 | 85 |
| " | 1 | Dog biscuits | 1.39 | 0.30 | 1.06 | 76 |

Both adult and juvenile mice consumed larger quantities of sheep nuts than dog biscuits per day in the experimental situation. At least in part this may be because they are easier for a mouse to break up and ingest, being less compacted than dog biscuits. This is also indicated by the large quantities of sheep nuts which were shredded but not consumed as shown by their low "consumption efficiency" (i.e., ratio of food consumed to food consumed plus food chewed but spilled). This was 24% for sheep nuts compared with 55-75% for dog biscuits. Young mice on both diets had a much higher consumption rate than adults - almost twice as high in the case of sheepnut-fed mice. This presumably reflects their greater demand for energy for growth and the higher metabolic rate normally maintained by smaller individuals (Hansson and Grodzinski 1970).

Assimilation efficiencies ($A \times 100 : C$) were similar for mice of different ages fed the same food, but the assimilation of energy from sheep nuts was 8-9% more efficient than that from dog biscuits. This suggests that dog biscuits have a higher fibre content as this largely determines the proportion of consumed food digested (Meese 1971). The assimilation efficiencies obtained here are quite high but are comparable with those given by Meese

for the vole *C. glareolus* fed on similar foods.

GROWTH

Mean growth (weight increase) of three litters of mice, two fed dog biscuits and one fed sheep nuts, is shown in Fig. 1. Also given are individual growth curves for four adult mice kept with the 1971 litter, and the mean growth curve for a litter of four produced by one of these mice. The mean growth rate of all litters was similar and almost linear until a weight of 17-20 g

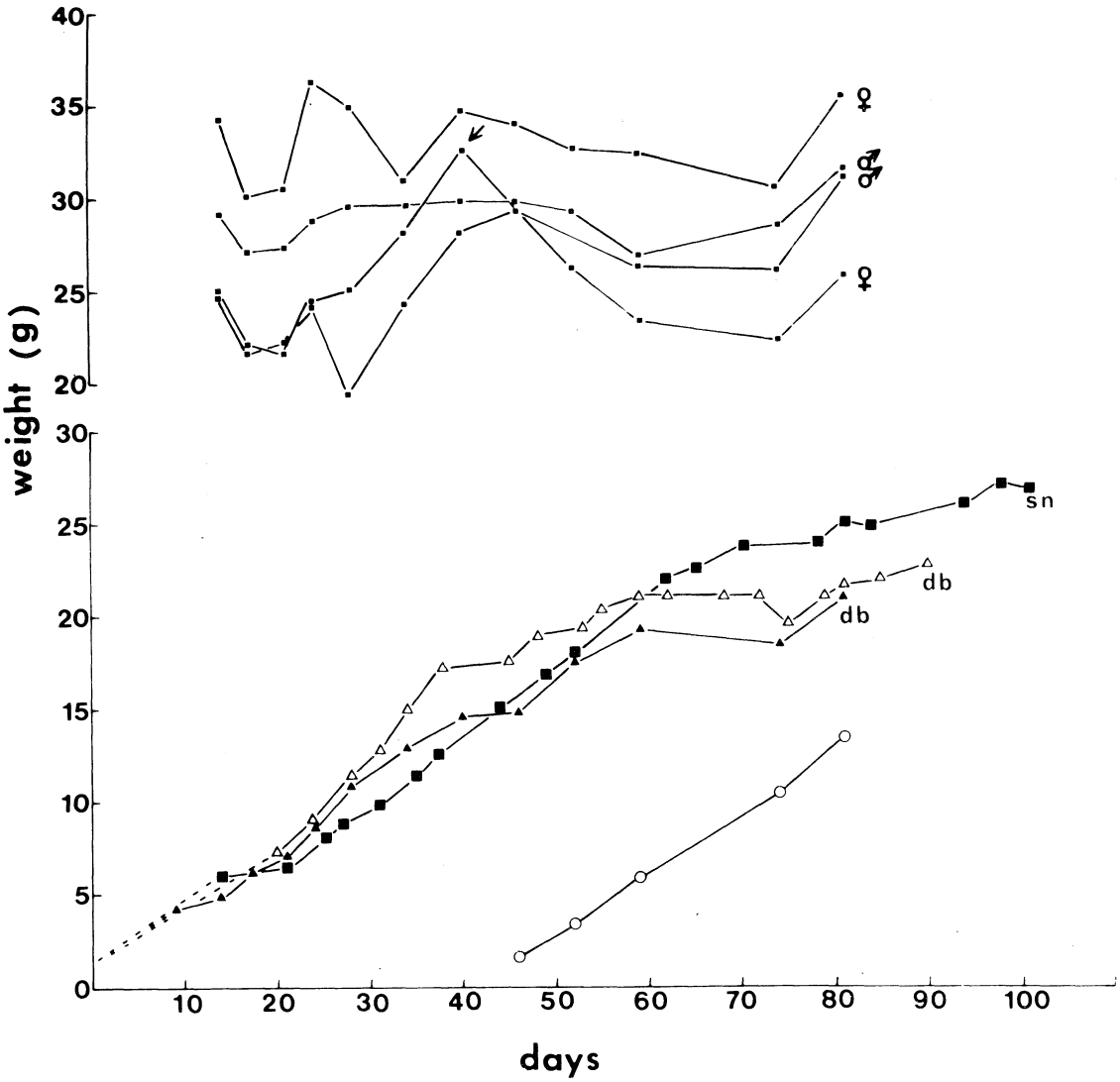


Fig. 1. Mean growth of four litters of mice and individual growth curves for four adult mice.
sn = sheep nut fed 1972; db = dog biscuit fed, closed triangles 1971, open triangles 1972; open circles litter produced by female at the point indicated by an arrow; broken sections of curves show growth extrapolated back to birth.

was attained at an age of almost 60 days. Little growth of dog biscuit-fed mice occurred after this but sheepnut-fed mice continued to grow at a reduced rate and attained a mean weight of almost 27 g when 101 days old.

Food consumption by the two 1972 litters over the full experimental period was estimated from the amount of food offered and the experimentally determined food spillage factor. In this way a mouse was estimated to have consumed an average of 13.3 kcal dog biscuits per 17 kcal sheepnuts per day over the period of investigation. As the mean weight of a dogbiscuit-fed mouse over this period was 17.8 g and that of a sheepnut-fed mouse 17.7 g an average of 0.75 kcal and 0.96 kcal were consumed per g mouse per day respectively. When compared with the consumption estimates obtained in the short term feeding experiments (Table 2) these values are found to be a little lower than those calculated for adult (about 20 g) mice. Despite the probability of error arising from use of the spillage correction, the results obtained by the two methods are remarkably similar.

Weights of adult mice fluctuated widely over a 67 day period. One female which produced a litter during this time increased its weight by 12 g in the 19 days prior to parturition. This time represents the normal gestation period for mice at 21°C (Pennycuik et al 1968).

Twenty four hour experiments during which mice were deprived of food and/or water (Table 3) indicated that several grams would be lost in that time if animals did not feed, and lesser amounts would be lost if they did not drink. Variations in intensity of feeding and drinking and proximity of feeding times to the time of weighing, in addition to changes in reproductive condition could therefore have accounted for most fluctuation in weight by adult mice during the study period.

TABLE 3. WEIGHT CHANGES OF MICE DEPRIVED OF FOOD AND/OR WATER IN 24-HOUR EXPERIMENTS

Four mice in each group. Results given as means and ranges.

| Regime | Initial weight (g) | Weight change after 24-hr (g) | Mean change as % initial weight |
|---|---|---|---|
| Food only | 22.0 (19.7 - 27.0) | -1.6 (-1.2 - -1.9) | -7.1 |
| Water only | 20.0 (17.4 - 25.4) | -2.7 (-1.5 - -4.2) | -13.7 |
| Food and water | 21.9 (16.4 - 27.7) | +0.3 (-0.9 - +1.4) | +1.5 |
| Nil | 22.0 (17.0 - 25.1) | -3.0 (-2.1 - -3.5) | -13.5 |

The weights of adult mice were well above those given by Barnett et al (1971) for wild adult females (including pregnant mice) of 20 g and males of 18 g which indicates that in cages more energy is channelled into growth.

METABOLISM

Adult mice used in respiration experiments (Table 4) had a mean weight of 25 g and in most cases they were either sleeping or exhibiting light activity (e.g., cleaning). The results

TABLE 4. RESULTS OF SHORT-TERM RESPIRATION EXPERIMENTS WITH PAIRS OF MICE IN CLOSED RESPIROMETERS

| Pair | Total exptl time (min) | No. of readings | Combined wt of mice (g) | ml $O_2$ consumed | Respiration (kcal/g)/hr | Activity state |
|---|---|---|---|---|---|---|
| A | 45 | 4 | 40.0 | 153 | 0.024 | Resting |
| B | 45 | 4 | 52.4 | 161 | 0.020 | " |
| C | 5 | 1 | 50.0 | 25 | 0.029 | " |
| D | 16 | 8 | 57.0 | 64 | 0.020 | " |
| E | 18 | 9 | 55.0 | 93 | 0.027 | " |
| F | 48 | 3 | 40.0 | 120 | 0.018 | Sleeping |
| C | 28 | 2 | 50.0 | 86 | 0.018 | " |
| F | 5 | 1 | 40.0 | 30 | 0.043 | Highly active |
| G | 45 | 3 | 17.7 | 102 | 0.037 | Resting |

obtained are probably a close approximation to the resting metabolic rate (*RMR*). On this assumption a mean *RMR* of 0.022 (kcal/g mouse)/hr (0.53 (kcal/g mouse)/day) was calculated. This is slightly lower than the values obtained at 20°C and 28-33°C by Grodzinski and Gorecki (1967) but within the range of values obtained by Pearson (1947) and Pennycuik (1967) for similar sized mice at comparable temperatures.

The *RMR* for a pair of young mice averaging 8.9 g was almost 1.7 times that for adult mice. This is similar to the situation found in the field vole *Microtus agrestis* for which a 1.9 times increase in *RMR* should occur over this size range (Hansson and Grodzinski 1970).

The maximum metabolic rate obtained in this study was for 5 minutes of high activity and was almost twice the *RMR*.

ENERGY BUDGETS

Results obtained from the above experiments have been combined in the form of 24 hr energy budgets for hypothetical mice weighing 12 and 25 g and fed the two experimental foods (Table 5).

In developing a 24 hr energy budget the most useful measure of respiration is not the *RMR* but one representing the average daily metabolic rate (*ADMR*). Without making continuous recordings of respiration throughout a day this can be estimated from short term determinations of *RMR* and knowledge of the rate of energy assimilation derived from feeding experiments. Previous studies (Odum et al 1962, Haberman and Fleharty 1971) have shown that values for metabolized energy obtained by the food consumption method are often approximately double those obtained by the oxygen consumption method. Haberman and Fleharty (1971) have

TABLE 5. TWENTY-FOUR HOUR ENERGY BUDGETS CALCULATED FROM 4 "REPRESENTATIVE" MICE WEIGHING 12 AND 25 g AND FED SHEEP NUTS AND DOG BISCUITS

All results expressed as (kcal/g mouse)/day

| Mouse | A | B | C | D |
|---|---|---|---|---|
| Weight (g) | 25 | 12 | 25 | 12 |
| Food | sheep nuts | sheep nuts | dog biscuits | dog biscuits |
| Consumption | 26.0 | 24.24 | 21.75 | 16.60 |
| Egestion | 2.75 | 2.40 | 4.25 | 3.60 |
| Assimilation | 22.35 | 20.64 | 16.75 | 12.72 |
| Urine | 0.39 | 0.64 | 0.52 | 0.39 |
| Respiration | | | | |
| a) RMR | 13.20 | 9.79 | 13.20 | 9.79 |
| b) ADMR | 12.77 | 15.22 | 14.97 | 11.26 |
| Growth* | 0 | 0.6 | 0 | 0.6 |

*No growth assumed for 25 g mice. Growth of young mice assumed to be 0.4 g per day (from Fig. 1). Calorific value of mouse tissue taken as 1.5 kcal/g live mouse.

suggested using oxygen consumption data for resting energy values, and food consumption data for metabolized energy used in activity when extrapolating from experimental to "field" conditions. This has been done here, and the day divided into two 12 hr periods of rest and activity. Pearson's (1947) study of mouse activity suggests that this is probably a reasonable assumption.

In a perfectly balanced energy budget assimilation will equal *ADMR* in a non-growing animal, or *ADMR* plus growth in a growing individual. In the four budgets presented here perfect balance has not been achieved and in all cases the assimilation value is higher, although negigibly so for Mouse D.

The main generalizations arising from this study are that when fed sheep nuts, mice tended to consume more food per day and that energy flow through these mice was greater than through those fed dog biscuits. In other studies on small mammals, energy flow has also been found to vary with differences in diet, Meese (1971) noting that energy flow values between 0.23-0.96 (kcal/g)/day. For the bank vole *C. glareolus*, Meese obtained values ranging from 0.23 (fed acorns) to 0.73 (fed oats) (kcal/g) /day. Energy flow through adult *M. musculus* in the present study was within the range quoted by Meese, but was greater through young mice, particularly those kept on the sheep nut diet (1.72 (kcal/g)/day). Most assimilated energy is used in metabolism rather than growth and a high proportion of this metabolic energy is probably used in heat production for thermoregulation which, according to Grodzinski and Gorecki (1967), is the main item in the energy budget of a rodent.

The ratio of production to assimilation in young mice was calculated to be 4.7% (dogbiscuit-fed) and 2.9% (sheepnut-fed), very similar to the figure of 3.1% given by Brown (1963) for an

increasing laboratory population of mice.

As growth rates of young mice fed both foods were similar, and as the fat content of young adult mice was also similar it seems that sheepnut-fed mice must have been using a greater amount of energy for metabolism. This may have been due to greater general activity of these mice, a suggestion which is supported by casual observations and is in agreement with Meese's (1971) claim that there may be reduction of activity on diets where the energy intake is low.

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